ANALYSIS OF WEAR RESISTANCE OF TOOL STEEL

AFTER DEEP CRYOGENIC TREATMENT

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ABSTRACT

In the present research work T42 HSS material is used for evaluating effect of turning process parameters on tool wear. Further the same tool material is used for evaluating effect of cryogenic treatment along with turning process parameters on tool wear. The results led to a conclusion that there is an improvement in wear resistance of cryogenically treated tools as compared to the conventionally treated tools. Taguchi's modified L8 array is used for carrying out experiments. The results obtained from non cryo tools and cryo treated experimentations are used to develop empirical mathematical models, comparison of wear etc. The experimental results obtained in case of non cryo and cryo treated tools experimentations are used to plot nomographs for prediction of wear. The mathematical model developed in this research work can be used to find out the improvement in wear resistance due to cryogenic treatment temperature, which ultimately is useful in determining the improvement in tool life due to cryogenic treatment.

KEYWORDS: Nomgraphs, Cryogenic Treatment, Tool Wear

INTRODUCTION

Metal cutting processes are widely used to generate different shapes and sizes of workpieces as per our requirements.A metal cutting process basically needs a work material, a cutting tool and a machine tool to provide appropriate motions to the workpiece and cutting tool. Hardness of cutting tool is essentially required to be more than that of the workpiece. Relative motion between the workpiece and cutting tool removes material from the workpiece. Depending on the nature of relative motion metal cutting processes are classified as turning, shaping, drilling etc.Turning is one of the most widely used metal cutting processes. Tool wear is one of the important criteria for deciding tool life. Economics of metal cutting processes largely depends on tool life. The properties of the tool material such as hardness, red hardness, wear resistance etc. play an important role in deciding tool life. Efforts are continuously being made to improve these properties so as to have more tool life. Improvement in tool life ultimately reduces cost of production.

BACKGROUND

In a review carried out by R. F. Baron [1] on cryogenic treatment to various materials including M2 HSS observed significant improvement in the wear resistance. The M2 steel was cryogenic treated at Œ84 ^{0}C) and soaked for 24 hrs. He also found that the wear resistance further increased when cryogenic temperature was -196^{0}C.Fanju Meng et. al. [2] in their experimental work used alloy tool steel with composition (wt %), 1.44C, 0.3Si, 0.4Mn, 12.2Cr, 0.84Mo, 0.43V, 0.022P, and 0.008S for wear test. After heat treatment cold treatment at 2230K and cryogenic treatment at 930K were

carried out. Figure 2.2 shows a typical heat treatment cycle of experiments. Tempering was carried out at 453K for 600s after cold treatment and cryogenic treatment. J. D. Darwin et. al. [3] used Taguchi™s method for optimization of cryogenic treatment to maximize wear resistance of chrome silicon spring steel. Sample of piston rings made of chrome silicon spring steel SR10 were cryogenic treated using different factors such as cooling rate, soaking temperature, soaking period, tempering temperate and tempering period. L9215 array was used for the first experiment set up and L934 for the second set up. All samples were subjected to sliding wear test. S. K. Choudhary et. al.[4] developed an empirical mathematical model for measurement of tool wear using cutting parameters such as cutting speed, feed, depth of cut and the force ratio in case of turning operation. A series of experiments were conducted using C45 workpieces and HSS tool. Lee et. al. [5] carried out work for obtaining the optimal tool life with the ratio of cutting speed to flank wear value. He claimed that the results have shown a good correlation between the dynamic tangential force and flank wear.

EXPERIMENT

Initially selection of the tool material for the present is discussed at length. It is then decided to establish effect of various combinations of cryogenic temperatures and soaking time on selected tool steel. After studying the results of the pilot experiments further experiments for non cryo tools are planned and performed using the procedure of Taguchi's orthogonal arrays (O.A.), a modification to the technique of Design of Experiments (DoE). Flank wear of tool is considered as the output variable (response). The results obtained from main experimentations are confirmed by carrying out confirmatory experiments. The entire procedure stated above for non cryo tools is repeated for cryo treated tools by adding cryogenic treatment as one more step. Materials and test conditions. All tool steels contain manganese, generally 0.2-0.4 % when not listed. Tool steels usually contain silicon 0.2-0.35% [6].

Selection of Tool Material

Tool Steels are carbon and alloy steels containing over 0.6 % C, having high hardness (60 to 65Rc), strength and wear resistance. These steels are used for making various cutting, measuring and other tools. Compositions of tool steels: Table 1 shows the composition limits for the some of the tool steels commonly used today [6]. Basically there are two classifications of High speed steels: Molybdenum HSS (group M) and Tungsten HSS (Group T). Both the groups of HSS are equivalent in performance; the main advantage of group M is their initial lower cost than group T steels [7].

Table 1: Compositions of Some of the M and T Type Tool Steels [6]

Material	% Composition								
	C	Mn	Si	Cr	Ni	V	W	Mo	Co
M1	0.8	-	-	4.4	-	1.1	1.5	8.5	-
M2	0.85	-	-	4.0	-	2.0	6.0	5.0	-
T1	0.7	-	-	4.0	-	1.0	18.0	-	-
T15	1.5	-	-	4.0	-	5.0	12.0	-	5.0

Tool Geometry

The heat treated T42 samples are then ground for a size of 16 mm x 16 mm x 60 mm long on a surface grinding machine. The geometry provided for the tools is made a combination of the elements of the tool geometry provided by many of the researchers while carrying out their research [4].

Table 2

Back rake Angle:-10^0	End Cutting Edge Angle:8^0
Side rake angle: 10^0	Side cutting edge angle:0^0
End relief angle:10^0	Nose radius:0.4 mm
Side relief angle:5^0	

Work Material

As per the literature review & detailed market survey a material AISI 1018 is finalized. Two AISI 1018 bars of diameter 50 mm and length 5.4 meters are procured as a work material. The chemical composition analysis carried out for AISI 1018 workpiece material is depicted in Table 4.7.

Table 3: Chemical Composition of Work Material AISI 1018

C	Mn	S	P	Si	Ni
0.166%	0.64%	0.047%	0.034%	0.19%	0.02%

CNC Machine Set Up

As constant cutting speed is required, Computer Numerically Controlled (CNC) lathe is the most suitable option for the experimentations. CNC lathe also maintains feed and depth of cut values to a good accuracy level. After a detailed survey in different industries ACE make CNC lathe, Jobber-XL 2728 type is found suitable for the experimentations.

A programme in G codes is fed to the Fanuc control panel and turning operations are carried out as per the programmed instructions.

RESULTS AND DISCUSSIONS

In Taylor's equation tool life is considered as affected only by cutting speed. Other process parameters are neglected. It is observed that the feed and depth of cut also affect on wear of the tool, i. e. on tool life. These factors also contribute to wear of the tool. Hence tool life can be said to be function of cutting speed, feed and depth of cut and can be mathematically expressed as TL = f (V, f, d)

Where V is cutting speed in m/min, TL is tool life in min, f is feed in mm/rev, d is depth of cut in mm, n is exponent of the curve between cutting speed and tool life, x is exponent of the curve between feed and tool life, y is exponent of the curve between depth of cut and tool life and C1 is constant dependent on work material.Equation 2 can be also be written as which can be further written as An empirical relationship between these factors is established and is known as extended Taylor's equation [3,4]

$$V (TL)^{n} f^{x} d^{y} = C1 \tag{2}$$

$$TL = a_0 . V^{a1} . f^{a2} . d^{a3} \tag{3}$$

Where

$a_0 = (C1)^{1/n}$, a1 = - (1/n), a2 = - (x/n) and a3 = - (y/n) are constants.

Mathematical Model to Evaluate Wear of a Non Cryo Tool

There are various methods to determine tool life data. As suggested by Taylor, if wear land is considered to be constant, the wear-land curves as shown in Figure 3.6 can be extrapolated to determine tool life [1, 4]. An equation can be

written for tool life in terms of wear using these curves as [1]

TL =w1 - w'/kw   (4)

where w1 is wear land failure criterion, w' is the wear land intercept found experimentally and kw is wear land growth rate.Tool wear w and cutting time t mathematically can be expressed [1] as

w = wo + mt   (5)

Where w0 is initial wear, m is slope of wear time curve and t is cutting time. Since an increase in wear is dependent on the given cutting conditions [1], tool wear can be expressed as

w = w0 + a0 . Va1. fa2 . da3 . ta4   (6)

A mathematical model for tool wear as a function of process parameters is proposed as

w = a0i. Va1i. f a2i. da3i   (7)

where w is tool wear, w0 is initial wear, V is cutting speed in m/min, f is feed in mm/rev, d is depth of cut in mm , t is cutting time in min, a0, a1, a2, a3 and a4 are constants. If machining time is constant, then tool wear can be said to be function of process parameters i. e. cutting speed, feed and depth of cut

i. e.   w = f (V, f, d)

where w is tool wear, V is cutting speed in m/min, f is feed in mm/rev, d is depth of cut in mm, a0', a1', a2', and a3' are constants, which can found out experimentally. In terms of logarithmic form equation 7 can be written as

$\log w = \log a_0' + a_1' \log V + a_2' \log f + a_3' \log d$ (8)

The wear of the conventionally treated tools shall be treated as of non cryo tool, which is denoted as wnoncryo.Henceequation 7 can be reproduced as

$_{wnoncryo} = a_0'. V_{a1}'. f_{a2}' . d_{a3}'$ (9)

By using equation 9 effects of process parameters on wear of non cryo tool can be evaluated for a tool work combination for a given setup.This is the mathematical model proposed for evaluating tool wear of a non cryo tool for constant machining time due to the selected process parameters.In terms of logarithmic form equation 9 can be written as

$\log w_{noncryo} = \log a_0' + a_1' \log V + a_2' \log f + a_3' \log d$ (10)

Mathematical Model to Evaluate Wear of a Cryo Treated Tool

It has been discussed in literature review that if cryogenic treatment is provided to a tool steel the wear decreases and, hence it can be said that tool wear is a function of cryogenic temperatures assuming constant soaking time for the treatment alongwith other process parameters for constant machining time. It can be mathematically expressed as

$w_{cryo} = f (V, f, d, Tc)$

Where w_{cryo} is wear of a cryo treated tool

A mathematical model for tool wear as a function cryogenic temperature and process parameters is proposed as

$w_{cryo} = b0'. Vb1'. f b2'. d b3'. Tc b4'$ (11)

where wcryo is wear of a cryo treated tool, V is cutting speed in m/min, f is feed in mm/rev, d is depth of cut in mm, Tc is cryogenic treatment temperature in ^{o}C and b0', b1', b2', b3' and b4' are constants, which can found out experimentally. This is the mathematical model proposed for evaluating tool wear of a cryo tool treated for constant machining time due to the selected cryo temperature and process parameters. In terms of logarithmic form above equation can be written as

i. e. $\log_{wcryo} = \log b_0' + b_1' \log V + b_2' \log f + b_3' \log d + b_4' \log Tc$ (12)

Mathematical Model to Evaluate Wear Resistance Improvement Due to Cryogenic Treatment

Equation 9 can be used to evaluate wear of the conventionally treated tool due to process parameters such as cutting speed V in m/min, feed f in mm/rev and depth of cut d in mm. Wear resistance improvement due to cryogenic treatment temperature can be mathematically given as

$w_{imp} = w_{noncryo} - w_{cryo}$ (13)

$w_{imp} = a_0'. Va_1'. f a_2'. da_3'' - b_0'. Vb_1'. f b_2'. d b_3'. Tc b_4$ (14)

Equation 14 can be used to find out wear resistance improvement of a cryo treated tool by cryogenic treatment temperature over a conventionally treated tool.As per the objectives of the proposed research work a mathematical model for evaluating wear resistance improvement of cryo treated tools is given by equation 14.As flank wear land is used as a measure of tool life in case of HSS tools, hence this percentage in wear resistance improvement of the tool due to cryogenic treatment can be considered as improvement in tool life of the tool.

PERFORMANCE ANALYSIS

The empirical mathematical models for evaluating tool wear from process parameters data for non cryo tools, for cryo treated tools and a comparison model for wear resistance improvement due to cryogenic treatment from the data obtained from experimentations, using regression analysis are established here.

Regression Analysis for Non Cryo and Cryo Treated Tools Wear

The data obtained from the non cryo tools and cryo treated tools experimentations is used for developing empirical mathematical models using Microsoft Excel software as discussed below:

Table 4.1: Regression Analysis Data for Non Cryo Tools

Cutting Speed, V (m/min)	Feed, f (mm/rev)	Depth of Cut, d (mm)	Tool Wear, $w_{noncryo}$ (mm)
75	0.075	0.3	0.223
75	0.125	0.5	0.443
80	0.075	0.5	0.323
80	0.125	0.3	0.388
85	0.125	0.3	0.424
85	0.075	0.5	0.344
90	0.125	0.5	0.491
90	0.075	0.3	0.288

Table 4.2: Regression Analysis Equations for Non Cryo Tools

	Linear Equation	**Non-Linear Equation**
General Equation	y = m1x1 + m2x2 +m3x3+ ...+ b	ln y = x1 ln m1 + .. + xn ln mn + ln b
	y =0.006983 x1 + 3.34167 x2+ 0.472918 x3 - 0.72092	ln y = x1 ln 1.018034 + x2 ln 7950.991 + x3 ln 3.54646 + ln 0.020476

Table 4.3: Regression Analysis Data for Cryo Treated Tools

Cryogenic temp.Tc (0C)	Cutting speed,V (m/min)	Feed, f (mm/rev)	Depth of cut,d (mm)	Tool Wear, wcryo (mm)
25	75	0.075	0.3	0.231
25	80	0.075	0.5	0.315
25	85	0.125	0.3	0.433
25	90	0.125	0.5	0.585
-80	75	0.125	0.3	0.305
-80	80	0.125	0.5	0.428
-80	85	0.075	0.3	0.251
-80	90	0.075	0.5	0.315
-140	75	0.125	0.5	0.393
-140	80	0.125	0.3	0.351
-140	85	0.075	0.5	0.298
-140	90	0.075	0.3	0.258
-185	75	0.075	0.5	0.198
-185	80	0.075	0.3	0.181
-185	85	0.125	0.5	0.483
-185	90	0.125	0.3	0.356

Table 4.4: Regression Analysis Equations for Cryo Treated Tools

	Linear Equation	**Non-Linear Equation**
General Equation	**y=m1x1+m2x2 +m3x3+... + b**	**ln y = x1 ln m1 + ... + xn ln mn + ln b**
	y=0.000386x1 + 0.006625 x2 + 3.1875 x3 + 0.403125 x4 - 0.65212	ln y = x1 ln 1.00114 + x2 ln 1.019603 + x3 ln 14841.24 + x4 ln 3.016076 + ln 0.017817

Note: Table 4.2 and 4.4 indicate the regression analysis results and the linear and non linear equations obtained for non cryo tools and cryo treated tools respectively. The data for this analysis is presented in Table 4.1 and 4.3 respectively. Here the dependent variable y represents the tool wear.

EXPERIMENTAL RESULTS AND GRAPHS

Non Cryo Tools

The results obtained form the non cryo tool experiments and measurements of tool flank wear are shown in Table

4.6. Y1, Y2 and Y3 refers to the response (flank wear) in the first, second and third replications respectively. The wear of the tool samples ranges between 0.220 mm to 0.605 mm. Table 4.5 also shows the arithmetic average values for the tool wear data.

Table 4.5: Experimental Results and Arithmetic Average of Tool Wear for Non Cryo Tools

Expt No.	Column No.			Actual setting values			Results Tool wear, w (mm)			Average Tool wear, w (mm)
	1	3	4	V (m/min)	f (mm/rev)	d (mm)	Set I Y1	Set II Y2	Set III Y3	
1	1	1	1	75	0.07	0.3	0.225	0.21	0.23	0.223
2	1	2	2	75	0.12	0.5	0.450	0.43	0.45	0.443
3	2	1	2	80	0.07	0.5	0.330	0.31	0.32	0.323
4	2	2	1	80	0.12	0.3	0.380	0.40	0.38	0.388
5	3	2	1	85	0.12	0.3	0.435	0.42	0.41	0.425
6	3	1	2	85	0.07	0.5	0.335	0.35	0.35	0.345
7	4	2	2	90	0.12	0.5	0.605	0.59	0.58	0.591
8	4	1	1	90	0.07	0.3	0.290	0.29	0.28	0.288

Figures 4.1 to 4.3 show the graphs of cutting speed verses tool wear, feed verses tool wear and depth of cut verses tool wear.
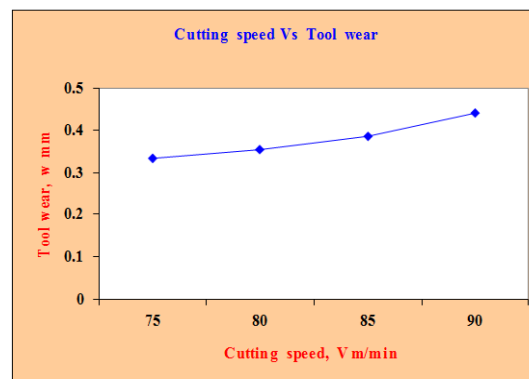

Figure 4.1: Cutting Speed Verses Tool Wear for Non Cryo Tools

From the figure 4.1 between cutting speed verses tool wear, it has been found that as cutting speed increases, the tool wear increases. The reasons for the increase in tool wear due to increase in cutting speed are analyzed as follows. At extremely slow cutting speeds the heat generated in machining operation is carried off in the chip and through the workpiece, tool and the atmosphere. Thus temperature of the cutting tool edge area goes on increasing causing more erosion of the tool particles, increasing wear of the tool.

Table 5

Cutting speed, V (m/min)	Feed, f (mm/rev)	Depth of cut,d (mm)	Tool Wear, wnoncryo (mm)
75	0.075	0.3	0.223
75	0.125	0.5	0.443
80	0.075	0.5	0.323
80	0.125	0.3	0.388

Table 5			
85	0.125	0.3	0.424
85	0.075	0.5	0.344
90	0.125	0.5	0.491
90	0.075	0.3	0.288

Figure 2 shows the graph of feed verses tool wear and indicates that as feed rate increase, tool wear increases.
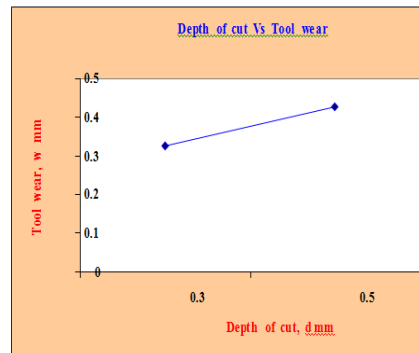

Figure 4.2: Feed Verses Tool Wear for Non Cryo

Also in case of depth of cut the tool wear increases as depth of cut increases as shown in Figure 4.3.The rate of increase in case of feed and depth of cut in the present experimentations is same *i. e.* depth of cut and feed has a ratio of 4 for both selected levels. Therefore, it can be concluded from observation of Figures 4.2 and 4.3 that, the rate of increase of tool wear due to feed is prominent as compared to depth of cut. This finding of the present work is in tune with the findings quoted in literature [9].

The results obtained from the confirmation experiments are compared for non cryo tools. The following data are considered for comparison Wear found out experimentally,

- Wear predicted by S/N ratio analysis

- Wear calculated from empirical model developed

The tool wear data as obtained from confirmation experiments for non cryo tools at optimum and non optimum condition are shown in Tables 4.6 (a) and 4.6 (b). The predicted tool wear using S/N ratio analysis and tool wear evaluated from the developed empirical mathematical model and corresponding S/N ratios shown in Table 4.6 (b).

Table 4.6 (A): Confirmation Experiments Result for Non Cryo Tools

Confirmation experiment combination	Chosen parametric values			Experimental results wear (mm)			
	V m/min	f mm/rev	d mm	Expt1	Expt2	Expt3	Average
Optimum	75	0.075	0.3	0.225	0.210	0.215	0.216667
Non optimum	90	0.125	0.5	0.595	0.580	0.600	0.591667

Table 4.6 (b): Results Comparison of Confirmation Experiments for Non Cryo tools

Experimental Results		Predicted Values		As Per Developed Model		% Error	
wear (mm)	S/N ratio	wear (mm)	S/N ratio	wear (mm)	S/N ratio	Predicted values	As per developed model
0.21666	13.2841	0.221543	13.0897	0.22432	12.9826	2.200927	3.53549
0.59166	4.55855	0.592708	4.43184	0.59196	4.55402	0.17681	0.05070
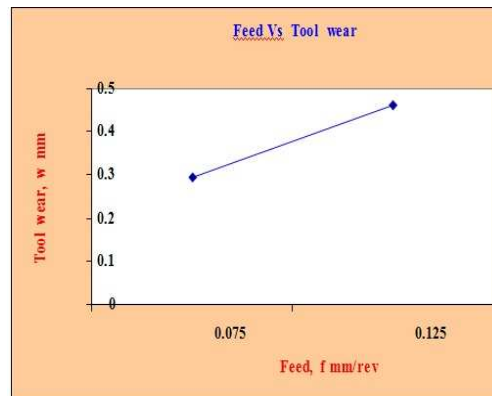
Figure 4.3: Depth of Cut Verses Tool Wear for Non Cryo Tools

Figure 4.4 shows the comparison of the experimental tool wear, predicted tool wear and wear evaluated from empirical mathematical model for non cryo tools. The error between actual measured wear and calculated form empirical mathematical model is only 3.53549 % for optimum condition confirmation experiments and 0.0507048 % only for non optimum condition experiments, which indicates a good validity of the empirical mathematical model developed for non cryo tools.
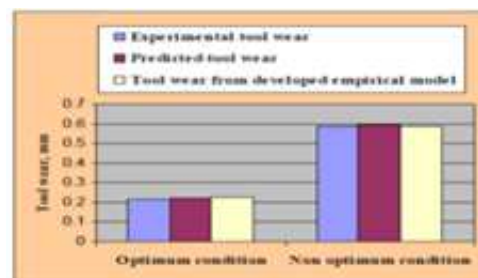

Figure 4.4: Comparison of Tool Wear for Non Cryo Tools

Cryo Treated Tools

The results obtained form the cryo treated tool experiments and measurements of tool flank wear are shown in Table 4.7. Y1, Y2 and Y3 refers to the response (flank wear) in the first, second and third replications respectively. The wear of the tool samples ranges between 0.170 mm to 0.590 mm. Table 4.7 also shows the arithmetic average values for the tool wear data.Figures 4.5 to 4.8 show the graphs obtained for cryogenic temperature, cutting speed, feed and depth of cut verses tool wear respectively.

Table 4.7: Experimental Results and Arithmetic Average of Tool Wear for Cryo Treated Tools

Expt No.	Column No				Actual setting values				Results Tool wear, w (mm)			Average Tool wear, w (mm)
	1	2	5	6	TC	V	f	d	Set I Y1	Set II Y2	Set III Y3	
1	1	1	1	1	25	75	0.075	0.3	0.240	0.220	0.235	0.232
2	1	2	1	2	25	80	0.075	0.5	0.310	0.320	0.315	0.315
3	1	3	2	1	25	85	0.125	0.3	0.445	0.430	0.425	0.433
4	1	4	2	2	25	90	0.125	0.5	0.585	0.580	0.590	0.585
5	2	1	2	1	-80	75	0.125	0.3	0.290	0.310	0.315	0.305
6	2	2	2	2	-80	80	0.125	0.5	0.440	0.420	0.425	0.428
7	2	3	1	1	-80	85	0.075	0.3	0.255	0.240	0.260	0.252
8	2	4	1	2	-80	90	0.075	0.5	0.325	0.315	0.305	0.315
9	3	1	2	2	-140	75	0.125	0.5	0.400	0.385	0.395	0.393
10	3	2	2	1	-140	80	0.125	0.3	0.360	0.350	0.345	0.352
11	3	3	1	2	-140	85	0.075	0.5	0.290	0.295	0.310	0.298
12	3	4	1	1	-140	90	0.075	0.3	0.245	0.270	0.260	0.258
13	4	1	1	2	-185	75	0.075	0.5	0.205	0.195	0.195	0.198
14	4	2	1	1	-185	80	0.075	0.3	0.190	0.170	0.185	0.182
15	4	3	2	2	-185	85	0.125	0.5	0.485	0.475	0.490	0.483
16	4	4	2	1	-185	90	0.125	0.3	0.355	0.360	0.355	0.357
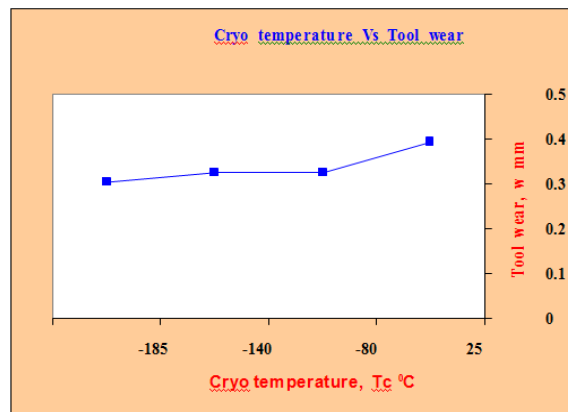
Figure 4.5: Cryogenic Temperature Verses Tool Wear for Cryo Treated Tools

The nature of the graph shows that the tool wear is reducing as the cryogenic process temperature is reduced. Lower the process temperature, lower is the wear of the tool. This clearly indicates that the wear resistance of the T42 tool material is improved as cryogenic temperature is reduced. This validates the
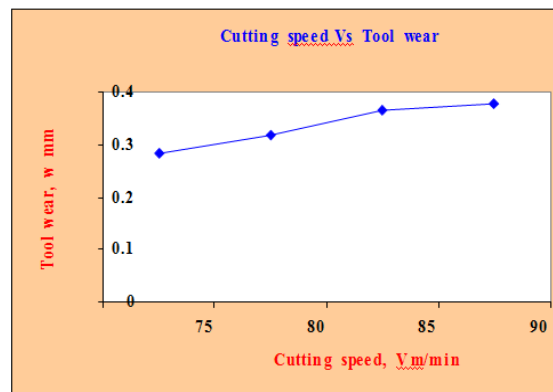
Figure 4.6: Cutting Speed Verses Tool Wear for Cryo Treated Tools

It can be seen from the graph that the rate of reduction of tool wear can be divided in two phases one phase upto Œ80 0C and then second phase from Œ80 0C to Œ185 0C.

Table 6

Experimental Results		Predicted Values		As per Developed Model		% Error	
wear (mm)	S/N ratio	wear (mm)	S/N ratio	wear (mm)	S/N ratio	Predicted values	As per developed model
0.171	15.0	0.16	13.0	0.177	15.0	2.71	3.1881

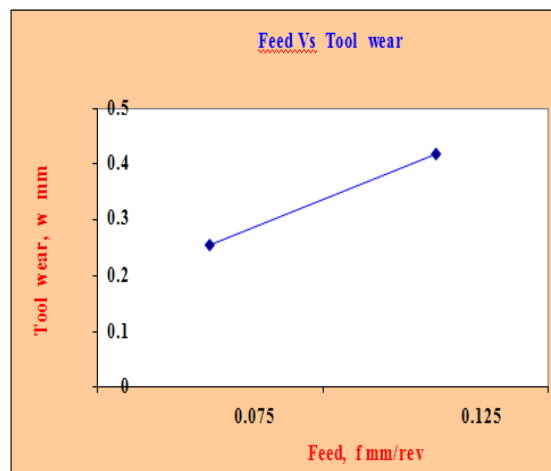**Figure 4.7: Feed Verses Tool Wear for Cryo Treated Tools**

The reduction in wear upto Œ80 0C is higher as compared to reduction of wear of from 80 0C onwards. After Œ80 0C the wear is reduced but the rate of reduction is lower. The effect of cutting speed, feed and depth of cut on tool wear already discussed above for non cryo tools is also applicable to cryo treated tools as can be seen from Figures 4.6 to 4.8 respectively.
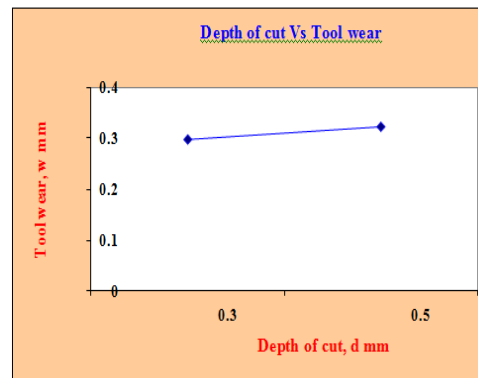
Figure 4.8: Depth of Cut Verses Tool Wear for Cryo Treated Tools

The cryo treated tools show reduction in wear of the tools *i. e.* there is improvement in wear resistance of the T42 tool steel due to cryogenic treatment. This improvement in wear resistance leads to improvement in life of the tool. The following data are considered for comparison

- Wear found out experimentally,

- Wear predicted by S/N ratio analysis

- Wear calculated from empirical model developed

The tool wear data as obtained from confirmation experiments at optimum are shown in Tables 4.9 (a) and 4.9 (b). The predicted tool wear using S/N ratio analysis and tool wear evaluated from the developed empirical mathematical model and corresponding S/N ratios are shown in Table 4.9 (b). The non optimum condition for the cryo tools is same as for non cryo tools.

Table 4.8 (a): Confirmation Experiments Result for Cryo Treated Tools

experiment combination	Chosen parametric values				Experimental results wear (mm)			
	TC ^{0}C	V m/min	f m m/rev	d mm	Expt1	Expt2	Expt3	Average
Optimum	-185	75	0.075	0.3	0.17	0.165	0.17	0.1716

Table 4.8 (b): Results Comparison of Confirmation Experiment for Cryo Treated Tools

Experimental results		Predicted values		As per developed model		% error	
wear (mm)	S/N ratio	wear (mm)	S/N ratio	wear (mm)	S/N ratio	Predicted values	As per dev.model
0.17	15.03	0.16	13.0	0.17	15.03	2.718	3.18

The error between actual measured wear and calculated form empirical mathematical model is only 3.1881491 % for optimum condition confirmation experiments, which indicates a good validity of the empirical mathematical

model developed for cryo treated tools.

Table 8

Confirmation experiment Combination	Chosen Parametric Values				Experimental Results Wear (mm)			
	TC ^{0}C	V m/min	f mm/rev	d mm	Expt1	Expt2	Expt3	Avg
Optimum	-185	75	0.07	0.3	0.17	0.16	0.17	0.171

Figure 4.9 shows the comparison of the experimental tool wear, predicted tool wear and wear evaluated from empirical mathematical model for cryo treated tools. The non optimum condition for cryo treated tools is same as that of non cryo tools
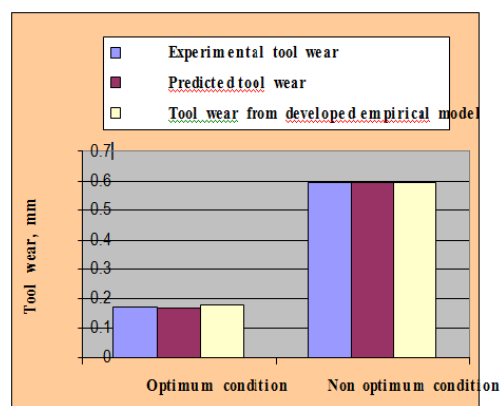

Figure 4.9: Comparison of Tool Wear for Cryo

Treated Tools

CONCLUSIONS

- A mathematical model for tool wear as a function of turning process parameters is proposed.

- Also, a mathematical model for tool wear as a function of cryogenic treatment temperature along with turning process parameters is proposed.

- A regression model for evaluating tool wear of non cryo tools due to turning process parameters is evolved using non linear regression analysis. As the coefficient of determination R2 for the developed model is 0.997522, it indicates a very good validity of the model developed.

- Out of the three process parameters cutting speed has highest effect on tool wear followed by feed and depth of cut.

- A regression model for evaluating tool wear of cryo treated tools due to cryogenic treatment and turning process parameters is also evolved using non linear regression analysis. In this case also very good validity of the model developed is indicated, as the coefficient of determination R2 for the developed model is 0.951487.

- An empirical mathematical model to evaluate effect on tool wear of T42 tool material due to cryogenic temperature is evolved as a difference between the models developed for non cryo tools and cryo treated tools.

- The wear resistance improvement in case of T42 HSS material due to cryogenic treatment temperaturesas calculated from the developed empirical mathematical.

- Nomographs are plotted for both non cryo tools as well as cryo treated tools.

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